

DETECTING CONCEALED OBJECTS AT A CHECKPOINT

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. Patent Application No. 10/301,552 filed 21 November 2002, which is a continuation of U.S. Patent Application No. 09/810,054 filed 16 March 2001 (now U.S. Patent No. 6,507,309). The present application is also related to U.S. Patent Application No. 10/607,552 filed 26 June 2003. The above-indicated patent and patent applications are each hereby incorporated by reference.

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GOVERNMENT RIGHTS

This invention was made with Government support under Contract Number DE-AC0676RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

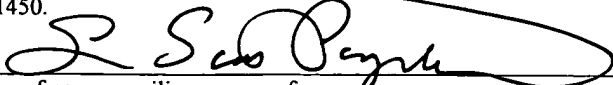
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BACKGROUND

The present invention relates to electromagnetic radiation scanning/imaging techniques, and more particularly, but not exclusively, relates to detecting concealed objects carried by a person under clothing.

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The detection of weapons, contraband, and other concealed objects is of significant interest at security checkpoints and the like. One approach utilizes a magnetometer to detect certain metallic objects. Unfortunately, this approach does not detect most organic polymer and composite materials that may be used to fabricate
5 firearms, explosives, and other items that may pose a security threat.

In another approach, electromagnetic radiation within a selected wavelength range can be applied to provide images that can reveal objects hidden by clothing. However, this approach typically faces limitations regarding interrogation speed and/or image resolution that has made it undesirable for some applications – such as certain mass
10 transit security checkpoints. Moreover, because these systems can provide detailed images of body parts that are ordinarily intended to be hidden by clothing, utilization of a human inspector can be embarrassing to the person being inspected, and may pose a concern that privacy rights are being violated. Thus, there is an ongoing demand for further contributions in this area of technology.

SUMMARY

One embodiment of the present invention is a unique technique to detect objects. Other embodiments include unique systems, devices, methods, and apparatus to
5 determine if a person is concealing an object.

A further embodiment of the present invention includes a technique to scan a person with electromagnetic radiation and determine if an object is being carried by the person. This determination can be made by evaluation of image data from the scan, which may include inspection of one or more corresponding images by an operator. In
10 one form, an operator inspects one or more cross sectional views of the person taken along the person's height to minimize privacy concerns that might arise from imaging of body features that are normally hidden to the public.

In another embodiment, a person is irradiated by electromagnetic radiation within a frequency range of about 200 Megahertz (MHz) to about 1 Tetrahertz (THz). Data
15 representative of an image of the person is established from the irradiation and corresponding image data is provided. In one form, the irradiation is performed with a pair of arrays that each follow a path that turns about the person. In one specific implementation of this form, each array is provided as a pair of opposed panels that each curve about the person. These panels can be used to provide a security checkpoint, and
20 may be used in conjunction with one or more other devices to restrict access of individuals.

In still another embodiment, the system includes two or more arrays spaced apart from each other to define an interrogation region therebetween. The arrays are structured

to turn about this region to interrogate a person or object with electromagnetic radiation at one or more frequencies in a range of about 200 MHz to about 1 THz. Also included are one or more processors operable to establish data corresponding to an image determined from one or more interrogation signals provided by the arrays. The one or
5 more processors generate an output as a function of this data. The system further includes a device responsive to this output to provide an indication to an operator if presence of a security-threatening object is suspected.

Yet another embodiment of the present invention includes: providing two or more arrays each shaped to turn about a person positioned between the arrays; operating
10 the arrays to perform an interrogation of the person with electromagnetic radiation at one or more frequencies in a range of about 200 MHz to about 1 THz; and generating image data from the interrogation to detect if the person is concealing an object.

A further embodiment of the present invention includes: generating electromagnetic radiation at one or more frequencies in a range of about 200 MHz to
15 about 1 THz with two or more arrays to perform an interrogation of a person positioned therebetween; moving at least one of the arrays along a nonstraight path about the person during the interrogation; and generating image data from the interrogation to detect if the person is concealing an object.

Still a further embodiment of the present invention includes performing an
20 interrogation of a person with electromagnetic radiation that has one or more frequencies in a range of 200 MHz to about 1 THz. One or more cross-sectional images of the person are generated based on the interrogation and it is determined if the person is carrying a concealed object that poses a threat to security from at least one of these images.

Accordingly, one object of the present invention is to provide a unique technique to detect items of interest.

Another object is to provide a unique system, method, device, or apparatus to determine if an object or material of interest is being concealed.

5 Other objects, embodiments, forms, features, advantages, aspects, and benefits of the present invention shall become apparent from the detailed description and drawings included herein.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a partial, diagrammatic view of a security inspection system.

Fig. 2 is a partial, top view of the Fig. 1 system along the view line 2—2 shown in Fig. 1.

5 Figs. 3 and 4 are flow charts illustrating one procedure for operating the system of Fig. 1.

Fig. 5 is a schematic, top view of the system of Fig. 1 illustrating a number of overlapping arc segments.

Fig. 6 is a partial, diagrammatic side view of a further system.

10 Fig. 7 is a partial, diagrammatic top view of the Fig. 6 system along the view line 7--7 shown in Fig. 6.

Fig. 8 is a comparative diagram illustrating various cross-sectional images generated in accordance with various techniques with the present invention.

Fig. 9 is a partial, diagrammatic view of another system.

15 Fig. 10 is a partial, cut-away view of the portal shown in Fig. 9.

Fig. 11 is a partial, diagrammatic view of still another system.

Fig. 12 is a partial, diagrammatic view of yet another system.

Fig. 13 is a partial, top view of the system of Fig. 12.

DETAILED DESCRIPTION

While the present invention may be embodied in many different forms, for the purpose of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

Fig. 1 illustrates security inspection system 20 of one embodiment of the present invention. In operation, system 20 interrogates an animate or inanimate object by illuminating it with electromagnetic radiation in the 200 Megahertz (MHz) to 1 Terahertz (THz) frequency range and detecting the reflected radiation. Generally, the corresponding wavelengths range from several centimeters to a few micrometers. Certain natural and synthetic fibers are often transparent or semi-transparent to such frequencies/wavelengths, permitting the detection and/or imaging of surfaces positioned beneath such materials. When the subject of interrogation is a clothed individual, image information about portions of a person's body covered by clothing or garments can typically be obtained with system 20, as well as those portions that are not covered by clothing or garments. Further, image information relative to objects carried by a person beneath clothing can be provided with system 20 for metal and nonmetal object compositions commonly used for weapons and contraband.

As illustrated in Fig. 1, body B is in the form of person 22 presented for interrogation by system 20. Person 22 is portrayed in a typical manner, being at least partially covered by garments or clothing designated more specifically by reference numerals 24a and 24b. Clothing items 24a and 24b conceal object 25 shown in the form of a weapon in phantom. Person 22 is positioned in scanning/illumination portal 30 of system 20. Portal 30 is configured for placement at a security checkpoint where it is desired to detect weapons and/or contraband. Portal 30 includes platform 32 connected to motor 34. Platform 32 is arranged to support person 22 or such other object desired to be examined with system 20. Motor 34 is arranged to selectively rotate platform 32 about rotational axis R while person 22 is positioned thereon. For the orientation shown, axis R is approximately vertical, and person 22 is in a generally central position relative to axis R and platform 32. In one form, platform 32 can be comprised of a material, such as an organic thermoplastic or thermoset polymer, that permits interrogation in or beneath the soles of shoes where weapons can sometimes be hidden.

Portal 30 further includes multiple element-sensing array 36. Referring additionally to the partial top view of Fig. 2, the relationship of platform 32 to array 36 is further illustrated. Axis R is generally perpendicular to the view plane of Fig. 2 and is represented by crosshairs. As motor 34 causes platform 32 to rotate about axis R, array 36 circumscribes a generally circular pathway P about axis R. Circular pathway P corresponds to an imaginary cylinder C with radius D. Radius D is the distance from axis R to array 36. In one preferred form, radius D is about 0.25 to about 3 meters. In a more preferred form, radius D is about 0.5 meters to 1.5 meters – corresponding to about a 1

meter to 3 meter diameter. Arrow A shown in Figs. 1 and 2 represents the selective rotation of platform 32 about axis R.

Sensing array 36 includes a number of linearly arranged elements 38 only a few of which are schematically illustrated and specifically designated by reference numerals to preserve clarity. Elements 38 each operate to transmit or receive electromagnetic radiation within a selected bandwidth. Sensing array 36 is coupled to processing subsystem 40. Subsystem 40 includes transceiver 42 with switching tree 43 coupled to elements 38 of array 36. In one form, the position of array 36 relative to platform 32 is determined with one or more positional encoders (not shown) that are coupled to subsystem 40. In other forms, one or more different position tracking devices and/or positioning tracking techniques can be used.

Under the control of transceiver 42, individual elements 38 can be selectively activated with switching tree 43. Each element 38 is dedicated to transmission or reception. Elements 38 are arranged in two generally vertical columns arranged in a back-to-back relationship with one another. Elements 38 comprising one of the columns are dedicated to transmission and elements 38 comprising the other of the columns are dedicated to reception. The number of elements 38 in each column is in a range of about 32 to about 2000 elements and spans a vertical distance of about 2 to 2.5 meters along axis R; however, in other embodiments, a different vertical span and/or number of elements can be utilized. Transceiver 42 can control switching tree 43 to irradiate body B with only one element 38 of the transmitting column at a time and simultaneously receive with one or more elements 38 of the receiving column. Transceiver 42 includes logic to direct successive activation of each element 38 of the transmitting column and the

corresponding one or more elements 38 of the receiving column to provide a scan of a portion of person 22 along a vertical direction with array 36. The corresponding “down range” or “time-of-flight” information can be used to provide positional data about a corresponding portion of person 22 under interrogation. Further information about such arrangements is provided in commonly owned U.S. Patent Number 5,859,609, which is hereby incorporated by reference.

In a preferred embodiment, transceiver 42 and elements 38 of array 36 are of a form suitable to transmit and/or receive electromagnetic radiation selected from the range of about one Gigahertz to about one Terahertz (about 1 GHz to about 1 THz), which corresponds to a free space electromagnetic radiation wavelength range of about 0.3 meter (m) to about 300 micrometers (μm). In another preferred embodiment, an impulse transceiver arrangement is utilized that generates frequencies in a range of about 200 MHz to about 15 GHz depending on the impulse width, which corresponds to a free space electromagnetic radiation wavelength range of about 1.5 m to about 0.02 m. In a more preferred embodiment, the frequency range is about 1 GHz to about 300 GHz with a corresponding free space wavelength range of about 0.3 meter to about 1 millimeter (mm). In a most preferred embodiment, the frequency range is about 5 GHz to about 110 GHz with a corresponding free space wavelength range of about 0.06 m to about 2.7 mm.

The transmission pathway for a given element 38 of the transmitting column can be selected to be about the same length as the transmission pathway for the corresponding element(s) 38 of the receiving column to simplify calibration. Nonetheless, in other embodiments, the transmission/reception arrangement can differ. For example, in one alternative embodiment, one or more elements 38 are used for both transmission and

reception. In another alternative embodiment, a mixture of both approaches is utilized. Typically, the signals received from array 36 are downshifted in frequency and converted into a processible format through the application of standard techniques. In one form, transceiver 42 is of a bi-static heterodyne Frequency Modulated Continuous Wave (FM/CW) type like that described in U.S. Patent Number 5,859,609 (incorporated by reference herein). Commonly owned U.S. Patent Numbers 5,557,283 and 5,455,590, each of which are incorporated by reference herein, provide several nonlimiting examples of other transceiver arrangements. In still other embodiments, a mixture of different transceiver/sensing element configurations with overlapping or nonoverlapping frequency ranges can be utilized that may include one or more of the impulse type, monostatic homodyne type, bi-static heterodyne type, and/or such other type as would occur to those skilled in the art.

Transceiver 42 provides the data corresponding to the array signals to one or more processors 44 of subsystem 40. Processor(s) 44 can each be comprised of one or more components of any type suitable to process the data received from transceiver 42, including digital circuitry, analog circuitry, or a combination of both. Processor(s) 44 can be of a programmable type; a dedicated, hardwired state machine; or a combination of these. For a multiple processor form; distributed, pipelined, and/or parallel processing can be utilized as appropriate.

Memory 46 is included with processor(s) 44. Memory 46 can be of a solid-state variety, electromagnetic variety, optical variety, or a combination of these forms. Furthermore, memory 46 and can be volatile, nonvolatile, or a mixture of these types. Memory 46 can be at least partially integrated with processor(s) 44. Removable

Memory Device (R.M.D.) 48 is also included with processor(s) 44. R.M.D. 48 can be a floppy disc, cartridge, or tape form of removable electromagnetic recording media; an optical disc, such as a CD or DVD type; an electrically reprogrammable solid-state type of nonvolatile memory, and/or such different variety as would occur to those skilled in the art. In still other embodiments, R.M.D. 48 is absent.

Subsystem 40 is coupled to motor 34 to selectively control the rotation of platform 32 with processor(s) 44 and/or transceiver 42. Subsystem 40 is housed in a monitoring/control station 50 that also includes one or more operator input devices 52 and one or more display devices 54. Operator input device(s) 50 can include a keyboard, mouse or other pointing device, a voice recognition input subsystem, and/or a different arrangement as would occur to those skilled in the art. Operator display device(s) 52 can be of a Cathode Ray Tube (CRT) type, Liquid Crystal Display (LCD) type, plasma type, Organic Light Emitting Diode (OLED) type, or such different type as would occur to those skilled in the art. Station 50 is arranged to be controlled by one or more security point operators responsible for the operation of system 20 as further described hereinafter.

System 20 further includes communication subsystem 60 coupled to subsystem 40 by communication link 62. Subsystem 60 includes network server 63 coupled to computer network 70. Computer network 70 can be provided in the form of a Local Area Network (LAN), a Municipal Area Network (MAN), and/or a Wide Area Network (WAN) of either a private type or publicly accessible type, such as the internet. Link 62 can be provided by such a network or be of a dedicated communication channel variety. Server 63 can be remotely located relative to subsystem 40. Indeed, in one embodiment,

server 63 is coupled to a number of remotely located subsystems 40 with corresponding portals 30. In still other embodiments, more than one server 63 can be coupled to a common portal 30 and subsystem 40 arrangement. Alternatively or additionally, server 63 can be an integral part of subsystem 40. For yet other embodiments, server 63,
5 network 70, and sites 80 are absent. Indeed, R.M.D. 48 can be used to alternatively or additionally transfer data between subsystem 40 and other computing/processing devices.

Server 63 is operable to communicate over network 70. Computer network 70 communicatively couples a number of sites 80 together. Each site 80 includes computer 82 arranged to communicatively interface with computer network 70. Each computer 82
10 includes one or more operator input device(s) 50 and one or more operator output device(s) 52 as previously described for subsystem 40, that are not shown to preserve clarity. Device(s) 50 and 52 at each site 80 selectively provide an operator input and output (I/O) capability. Computer 82 can be in the form of another subsystem 40, a personal computer or computer workstation, another computer server, Personal Digital
15 Assistant (PDA), and/or a different configuration as would occur to those skilled in the art. While only two sites 80 are illustrated to preserve clarity, it should be understood that more or fewer can be coupled via computer network 70.

Collectively, server 63, computer network 70, and sites 80 provide an arrangement to remotely communicate with station 50. The interconnection of these
20 components can be hardwired, wireless, or a combination of both. In lieu of or in addition to network 70, one or more of sites 80 and server 63 could be coupled by dedicated cabling or the like. Communication over network 70 can be used to monitor performance of station 50, update software associated with subsystem 40, remotely

operate station 50 or portal 30, and/or share data pertinent to the recognition of suspicious objects with system 20 as will be more fully described hereinafter. In one such arrangement, one or more of sites 80 are configured as a repository for data pertinent to security screening with system 20.

5 Referring additionally to the flowchart Fig. 3, one mode of operating system 20 is illustrated as procedure 120. Procedure 120 is performed with system 20 to provide image information representative of person 22 carrying object 25. Procedure 120 begins with operation 121. In operation 121, person 22 enters portal 30 at a security checkpoint to be screened for weapons, contraband, and/or other items/materials. Procedure 120
10 proceeds to initialization operation 122 that sets interrogation index "I" to one ($I=1$). From operation 122, procedure 120 enters interrogation loop 124 beginning with interrogation subroutine 130. Interrogation subroutine 130 interrogates a portion of person 22 within a field of view of array 36 as person 22 rotates on platform 32. Index I is an integer index to the number of different interrogation subroutines 130 performed as
15 part of procedure 120.

Referring to Fig. 4, interrogation subroutine 130 is further illustrated. Subroutine 130 begins with initialization operation 132 in which transmission index N is set to one ($N=1$). From operation 132, element sequencing loop 134 is entered, beginning with transmission/reception operation 136. Index N is an integer index to the number of
20 transmission/reception operations 136 performed during subroutine 130. In operation 136, a portion of person 22 in the field of view of a transmitting element number "N" of array 36 is irradiated with electromagnetic radiation and one or more corresponding reception elements collect the reflected electromagnetic radiation in response to the

transmission. The transmitting and reception elements are selected by logic of transceiver 42 with switching tree 43 as previously described. From operation 136, subroutine 130 proceeds to conditional 138, which tests whether transmitting element number "N" is the last element needed to transmit ($N=LAST?$); where LAST is the total
5 number of the transmitting elements to be activated by transceiver 42.

In one form, for each execution of subroutine 130, transmitting element "N" sweeps through a selected frequency range twice, and the corresponding backscatter information for each of the two sweeps is received with a different reception element. The transmitting elements can be staggered relative to the reception elements such that
10 transmitting element N aligns with a point between the two reception elements along a common axis of the array. U.S. Patent Number 5,557,283 (incorporated by reference) describes an example of this arrangement of transmitting and reception elements. In other forms, a different technique can be utilized involving more or fewer sweeps, different types of sweeps, and/or different transmitting/reception orientations and
15 numbers.

If the test of conditional 138 is negative ($N < LAST$), then increment operation 142 is performed, incrementing N by one ($N=N+1$). Loop 134 returns from operation 142 to transmission/reception operation 136 for execution with the transmitting/receiving subset of elements 38 corresponding to the new, incremented value of N from operation 142. In
20 this manner, elements 38 are activated in a vertical path along array 36 with transceiver 42 to provide data along a contiguous region of person 22.

The resolution of interrogation information obtained with transceiver 42 can be enhanced by linearly sweeping through a selected ultrawide frequency range during each

operation 136. In one preferred form, transceiver 42 sweeps through a range of at least 10 GHz for each execution of operation 136. This sweep can occur, for example, over a range of about 10 GHz to about 20 GHz. In a more preferred form, transceiver 42 and elements 38 are arranged for a sweep range of 16 GHz. This sweep can occur, for
5 example, over a range of about 24 GHz to about 40 GHz. In one most preferred form, the ultrawide sweep range is selected such that the range resolution is generally the same as the lateral resolution. For these forms, elements 38 are selected to be of a type with a frequency response suitable for the selected sweep range, including, but not limited to the taper slot or end-fire antenna type. In another form, the transmitter can sweep through a
10 given frequency range (such as 10 GHz to 20 GHz) in a pseudo-random order -- sometimes known as frequency hopping.

Loop 134 is repeated LAST number of times, sequencing through the desired transmitting/receiving elements 38 of array 36 under the control of transceiver 42. When the test of conditional 138 is true, the affirmative branch proceeds to data operation 144.
15 Data resulting from the execution of operation 136 is provided by transceiver 42 to processor(s) 44. In data operation 144, an interrogation data set is established for the information gathered through the repeated execution of operation 136 from $N=1$ through $N=LAST$. This data set corresponds to the current value of integer index I and the portion illuminated during these executions. Initially, the interrogation data set can be
20 accumulated and organized by transceiver 42, processor(s) 44 or both; and then stored in memory 46 for further processing by processor(s) 44 as described in connection with the remainder of procedure 120. From operation 144, subroutine 130 returns to the next stage of procedure 120.

Referring back to Fig. 3, procedure 120 continues with conditional 152 that tests whether the final value of index I has been reached ($I=TOTAL?$); where TOTAL is the total number of desired executions of loop 124 (and subroutine 130) for procedure 120. If the test of conditional 152 is negative ($I<TOTAL$), procedure 120 continues to
5 increment operation 154 to increment index I by one ($I=I+1$). Loop 124 then returns to subroutine 130 for the next execution until I is incremented to be equal to TOTAL.

With the execution of loop 124 TOTAL number of times, TOTAL number of interrogation data sets are stored in memory 46. When the test of conditional 152 is true, procedure 120 continues with cylindrical segmentation operation 160. In operation 160,
10 the interrogation data sets are processed with processor(s) 44 to generate a number of cylindrical image data sets that each correspond to an arc segment of cylinder C.

Referring to Fig. 2, arc segment S1 subtends a viewing angle V of about 90 degrees with respect to person 22. Arc segment S1 defines a cylindrical aperture CA that extends along axis R. The image data set corresponding to arc segment S1 represents the three-
15 dimensional surface of body B that is reflective with respect to the selected electromagnetic radiation, as if viewed through cylindrical aperture CA. In one convenient form, the image data set is defined in terms of cylindrical coordinates, although any three-dimensional coordinate system can be used. Each image data set is determined from the interrogation data gathered for the corresponding arc segment by
20 processor(s) 44. Reference is made to commonly owned U.S. Patent Number 5,859,609 (incorporated herein by reference) for further description about the determination of cylindrical image data.

During operation 160, cylindrical image data sets are determined for a number of arc segments about axis R that collectively circumscribe person 22. In Fig. 5, eight overlapping arc segments S1, S2, S3, S4, S5, S6, S7, and S8 (collectively segments S) are illustrated with respect the generally circular pathway P and corresponding cylinder C.

5 Segments S1, S3, S5, and S7 are schematically represented by double-headed arrows slightly to the outside of path P and segments S2, S4, S6 and S8 are schematically represented by double-headed arrows slightly inside path P to preserve clarity. In Fig. 5, segments S each correspond to a viewing angle of about 90 degrees, and each one overlaps two others by about 45 degrees. It should be understood that each different
10 segment S corresponds to a representation of a different portion of person 22. In other embodiments, the viewing angle can differ and/or may be nonuniform from one arc segment S to the next. Alternatively or additionally, overlap may be intermittent or absent.

Procedure 120 continues with mapping operation 162. In operation 162, the
15 image data obtained for the circumscribing arc segments S are mapped by processor(s) 44 to a common surface for body B, which in turn defines a common volume of body B. Operation 162 can include reconciling a data point for one of the arc segments S for a given location that differs by a threshold amount from the data point of the same location for another of the arc segments S. In one embodiment, an averaging technique is used
20 and intermediate data points are interpolated. In another embodiment, a weighting function is utilized that progressively reduces the contribution of a data point as the distance of that data point from the midpoint of the corresponding arc segment S increases. The cylindrical data sets are preferably combined incoherently (after

computing the magnitude) to reduce undesirable phase interference in the images.

Operation 162 provides a topographical representation of body B and the volume bounded by its surface(s) about axis R that are reflective with respect to the electromagnetic radiation used for the interrogations of subroutine 130.

5 Procedure 120 proceeds with operation 164. In operation 164, one or more images are determined with processor(s) 44 from the topographic representation of body B provided by operation 162. Operation 164 renders one or more two-dimensional images from the volumetric data for body B by performing a two-dimensional parallel ray projection from a desired viewing angle. Along each parallel ray, the intensity is
10 attenuated in proportion to the data it encounters in the volumetric representation. After attenuation, the maximum voxel intensity is selected to represent an image pixel intensity for the corresponding ray. The attenuation factor is adjusted so that the back surface of the representation does not contribute to the rendering. The two-dimensional rendering can be displayed using device(s) 52 as appropriate. In one embodiment, a number of
15 two-dimensional images from different viewing angles are rendered from the volumetric representation in operation 164. These images can be presented in a selected sequence to provide an animation of body B. In one form, a sequence of about 32 to about 64 generally evenly spaced views about axis R are used to generate a rotating animation of body B about axis R.

20 From operation 164, procedure 120 continues with the performance of object detection operation 170. In operation 170, a determination is made whether the person is carrying one or more objects of interest, such as those that may pose a threat to security. These objects may be completely or partially concealed by clothing of person 22. In one

form, the determination is initially performed by inspection of one or more images rendered in operation 164. Optionally, the suspect image features can be highlighted by a visual characteristic such as an identifying color, blinking/flashing or other intensity variation, and the like. Based on this display, an operator can determine if further inspection is warranted, if person 22 should be detained as a security risk, and the like. To hide/conceal body features to which a privacy objection might be made, the person's body can be provided as a schematic body image similar to a mannequin, a wire-frame body, or other gender-neutral representation. Alternatively or additionally, privacy concerns can be addressed by inspecting cross-sectional images taken along the height of person 22 to at least partially evaluate whether a suspicious object is potentially being carried. One approach to cross-sectional imaging is further described in U.S. Patent No. 6,507,309 (incorporated by reference), which is, instead, directed to gathering dimensional information about the sectioned region, such as its circumference. Other inventive aspects of sectional views are further described in connection with the experimental examples illustrated in connection with Fig. 8 hereinafter.

Optionally, visual and/or audible alert signals can be generated in operation 200 to focus the operator's attention on the person undergoing inspection and/or the corresponding image. Additionally or alternatively, information pertaining to the classification and detection of the objects can be displayed in text or graphic form for operator consideration. As another option, different views of the person and/or suspect image regions can be displayed simultaneously. In further variations, an operator can switch between different views and/or can zoom-in or zoom-out to change relative size of

an image being displayed using input device(s) 52. In still other embodiments, false alarms can be used to refine detection criteria as desired.

Alternatively or additionally, numerical processing of image data is performed to determine if one or more suspicious objects are being carried by person 22, such as
5 concealed object 25 shown in Fig. 1. In one form, adjacent image data of person 22 is processed by segmenting each into a number of overlapping portions. The size of a segment can be selected to be large enough to contain most of the region necessary to indicate a common object type of interest, but not so large as to make it difficult to localize such an object. For this form of automatic object detection, each segment
10 undergoes a Fourier transformation into Fourier spatial frequency space in accordance with operating logic of subsystem 40 to provide a corresponding spatial frequency representation for each image segment. Typically, such a representation is complex-valued. It has been found that man-made objects often have a spatial frequency representation that typically has a higher percentage of upper spatial frequencies relative
15 to natural objects, such as the human body. Also, spatial frequency representations for man-made objects tend to dominate in certain directions in a spatial frequency distribution over Fourier space. Such distinctions can be utilized to classify image portions suspected of revealing a man-made object.

Because spatial frequency information of the type provided by a Fourier
20 transform operation typically involves complex values, it is often desirable to simplify the data as part of the object detection procedure. An extraction filter can be applied to extract features from the spatial frequency representation that may be indicative of a man-made object. One type of feature extractor filter includes a ring-wedge

configuration, with a half-plane of wedges and a half-plane of rings centered on the zeroth (0^{th}) frequency component in Fourier space. For this extractor, the wedges provide scale invariance and the rings provide rotational invariance. Another extraction filter type is exclusively of a sector configuration. By integrating spatial frequencies within
5 each sector for this type, a set of features representing angular and radial aspects of the corresponding image segment can be generated. While not invariant, this extraction filter can be utilized to identify objects having preferred orientations and/or sizes. Still another extraction filter is of a ring configuration type that is rotation invariant and so represents a segment based on a radial spatial frequency component. One or more of these
10 extraction filter types can be applied and/or a different type of extraction filter may be utilized. In still other embodiments, extraction at this stage may be absent.

Continuing with this automatic detection example, extracted features during can be input into a neural network defined with subsystem 40. In one form, the extracted features are input into a multilayer perception form of neural network. The network is
15 configured for object identification through a repetitive training process, such as a back propagation of error algorithm. In still other embodiments, a different type of neural network and/or training technique may be additionally or alternatively utilized. In yet further embodiments, a different type of adaptive processing technique can be utilized in addition to or as an alternative to a neural network, such as fuzzy logic, an operator-
20 assisted expert learning system, or the like. Alternatively or additionally, nonadaptive processing can be utilized. If suspicious objects are indicated by a neural network or other automatic detection processing, then an image of each of the one or more detected objects can be displayed with output device(s) 54. The object image or images can be

shown using one or more previously described techniques to reduce privacy objections and/or can be shown with visual highlighting as previously explained.

After execution of operation 170, procedure 120 terminates. Despite the mode of determining if a suspicious object is present, the information gathered with subsystem 40
5 can be sent via computer network 64 to one or more remote sites 80. Sites 80 can perform some or all of the data processing of procedure 120 in lieu of processor(s) 44. In one process, a clothed individual is nonintrusively scanned by portal 30 and the image information is sent via server 63 and network 70 to a designated computer 82.

Alternatively or additionally, background information about a person carrying an object
10 of interest can be accessed via server 63 and network 70.

For procedure 120, transceiver 42 and processor(s) 44 include logic to perform the various operations described. This logic can be in the form of software programming instructions, firmware, and/or of a hardwired form, just to name a few. Furthermore such logic can be in the form of one or more signals carried with memory 46, R.M.D. 48,
15 and/or one or more parts of computer network 70. In one example, logic signals to perform one or more operations is transmitted to or from processor(s) 44 via network 70. Alternatively or additionally, programming for processor(s) 44 is transported or disseminated through R.M.D. 48 and/or one or more other storage devices.

Figs. 6 and 7 illustrate system 220 of a further embodiment of the present
20 invention that can be used to perform procedure 120. System 220 illuminates person 222 with selected electromagnetic radiation in the matter described in connection with system 20. For system 220, person 222 is wearing clothing articles that conceal object 225 shown in phantom. As in the previously described embodiment, system 220 can be used

to interrogate inanimate objects as well. System 220 includes dual clamshell panels 238 defining scanning portal 230 at security checkpoint 231.

System 220 also includes monitoring/control station 250 that is typically attended by one or more operators and coupled to panels 238 of portal 230. Station 250 includes
5 processing subsystem 240. Subsystem 240 can be configured the same as subsystem 40, accounting for differences in scanning techniques of portal 230, as is more fully described hereinafter. Station 250 also includes one or more operator input and output devices (not shown) as described in connection with system 20 that are coupled to
10 subsystem 240. Portal 230 includes stationary platform 232 arranged to support person 222. Platform 232 can be made of a material that is generally transparent to interrogation radiation. Portal 230 also includes an array 236 and a motor/drive mechanism 234 for each of panels 238. Array 236 is comprised at a column of elements 38 as described in connection with system 20. Mechanism 234 and arrays 236 are mechanically coupled to each other and are operatively coupled to subsystem 240. Under the control of subsystem
15 240, motor/drive mechanism 234 is configured to controllably move each of arrays 236 along a corresponding travel path P1 or P2 as best illustrated in Fig. 7. Notably, paths P1 and P2 are of a nonstraight, curvilinear type turning about axis Z. Axis Z is represented by crosshairs in Fig. 7 and corresponds to the vertical direction as best illustrated in Fig. 6. Correspondingly, arrays 236 each follow a path that turns about an interrogation
20 region 239 including platform 232 and person 222, when driven by the respective mechanism 234. Alternatively or additionally, either or both of paths P1 and P2 could be comprised of at least one straight path segment coupled to at least one other path segment in a curvilinear or angular manner. In still another arrangement, one or more of paths P1

and P2 are comprised of a number of straight path segments coupled together from one to the next at oblique angles to collectively turn about a portion of the interrogation region. In one particular form of this arrangement, the path segments are oriented to approximate an arc or other curvilinear shape. Further, while paths P1 and P2 are generally the same
5 length and symmetric about axis Z, in other embodiments paths P1 and P2 may not be the same length and/or may not be symmetric. In one alternative variation, more than two panels, arrays, and corresponding paths are utilized.

Mechanism 234 can include an electric motor or other controlled prime mover to drive a conveying arrangement for the respective array 236. Such an arrangement could
10 include a belt drive, a chain drive, a roller drive, or such other mechanized linkage as would occur to those skilled in the art to selectively make array 236. In other embodiments, a single prime mover may be utilized to which multiple arrays 236 in different panels are mechanically linked together to move in tandem. In further embodiments, another scanning arrangement could be utilized to transmit and/or receive
15 the desired range of electromagnetic energy.

In system 220, subsystem 240 is configured the same of subsystem 40 of system 20, and is likewise arranged to perform procedure 120, and can include one or more transceivers and/or switching trees as appropriate. However, during performance of procedure 120, the operation of subsystem 240 does not provide for interrogation
20 completely about the circumference of person 220. Instead, interrogation is performed over a partial circumference of less than 360° . The interrogation performed corresponds to angles A1 and A2 subtended by paths P1 and P2 as followed by arrays 236. In one preferred embodiment, angles A1 and A2 are each at least 90° . In a more preferred

embodiment, angles A1 and A2 are each 120° or less. In a further preferred embodiment angles A1 and A2 provide a circumference scan coverage of at least 240° about region 239. System 220 can include one or more encoders (not shown) operably coupled to system 240 and/or other devices/techniques to track position of arrays 236 relative platform 232. System 220 can further include a communication subsystem (not shown) the same as subsystem 60 to remotely communicate with subsystem 340.

In one particular arrangement, panels 238 are shaped and configured to house a respective one of arrays 236 that each are about seven feet in height, include 224 elements 38, and operate in the 10 to 20 GHz frequency range. More specifically, arrays 236 each include two subarrays of 112 elements 38 each. For each array 236, the corresponding subarray pair is arranged back-to-back. This arrangement utilizes two ultrawide transceivers, and two corresponding switching trees, one for each of arrays 236, to selectively transmit with one element 38 and receive with another element 38 in a desired sequence. A high-speed computer within subsystem 40 controls mechanisms 234, arrays 236, the transceivers, and the switching trees to obtain topographical data for processing in accordance with procedure 120. Panels 238 are opposite one another to provide an angular scanning range of about 240° for this arrangement. In one mode of operating this system, a person 222 under surveillance enters along the “ENTRY” arrow into region 239 between panels 238. Person 222 then turns and faces one of panels 238 for one to two seconds while arrays 236 move along paths P1 and P2 to perform the scan. Person 222 then turns and exits along the “EXIT” arrow after scanning. It is has been found that the 240° coverage provided by this approach is suitable to detect most objects that pose a threat to security. Panels 238 are each made to be at least partially transparent

to facilitate viewing therethrough by an operator during the interrogation of person 222 in region 239.

Referring to Fig. 8, cross-sectional images of mannequin 222a are shown as produced by laboratory simulation experiments performed in accordance with the present invention. Such cross-sectional images facilitate the detection of suspicious objects while reducing the likelihood of providing images to which a privacy objection might be made. Mannequin 222a is imaged in a number views in the columns 260, 270 and 280 taken with respect to different section lines 255a, 255b, and 255c of mannequin 222a. Cross-sectional images 260a, 270a, and 280a correspond to sections taken along section line 255a and transverse to axis Z. Likewise, cross-sectional images 260b, 270b, and 280b correspond to sections taken along section line 255b and transverse to axis Z. Further, cross-sectional images 260c and 280c correspond to sections taken along section line 255c and transverse to axis Z. The cross-sectional images 260a, 260b, and 260c shown in column 260 each correspond to a cross-sectional view along axis Z in which there is no object being carried and in which a full, 360° circumference is imaged. Images 270a and 270b of column 270 also provide full, 360° circumference cross-sections and further depict various threats concealed by clothing. Specifically, in cross-sectional image 270a, a small handgun 235 and dielectric slab 235a are detected. In cross-sectional image 270b, hand grenade 235b is detected. Images 280a, 280b, and 280c of column 280 each depict a 240-degree partial circumference view corresponding to one arrangement of system 220. In this system, the incomplete coverage (partial circumference) still reveals hand grenade 235d. It has been found that the arrangement of system 220 with less than

360° coverage provides a faster scanning and processing time that may be desirable in certain applications.

For this particular experimental arrangement of system 220, panels 238 are operated in an FM/CW mode with a 10-20 GHz sweep in less than 20 microseconds to provide an imaging resolution of about 1 centimeter and a range resolution of about 1.5 centimeters. During operation in this manner, arrays 236 are each provided in the form of two vertically-oriented subarrays arranged back-to-back. One subarray is dedicated to transmission and the other to reception. In one form, each subarray is fabricated with 112 elements of the slot-line antenna type. For each subarray, the elements are spaced apart from one another by a uniform distance. During operation, each subarray is electronically scanned from element-to-element as the scanner moves rapidly over the generally horizontal travel path P1 or P2. As the array moves, a number of scans are performed with only one element transmitting at a time and only one receiving reflective electromagnetic radiation due to such transmission. Each transmitting element and each receiving element is activated in accordance with a desired sequence during the scan. Nonetheless, in still other embodiments, a different number, size, or type of linear array arrangement can be utilized as would occur to those skilled in the art. In still other examples, different types of rotating and/or linear scanning arrays can be utilized separately or in combination. Further, as an alternative or addition to cross-sectional images, other types of images and/or automatic concealed object detection techniques can be utilized as described in connection with the embodiments of Figs. 1-5 to address privacy concerns.

Figs. 9 and 10 illustrate system 320 of another embodiment of the present invention that can be used to perform procedure 120. System 320 illuminates person 322 which selected electromagnetic radiation in the manner described in connection with system 20. For system 320, person 322 is wearing clothing articles that conceal object 325 shown in phantom. As in the previously described embodiment, system 320 can be used to interrogate inanimate objects as well. System 320 includes dual planar panel scanning portal 330 and processing subsystem 340 included in monitoring/control station 350. Portal 330 is coupled to processing subsystem 340 and can be configured the same as subsystem 40, accounting for differences in the scanning technique of portal 330 as is more fully described hereinafter. Station 350 includes one or more operator input and output devices as described in connection with system 20 that are coupled to subsystem 340. Station 350 can be arranged to provide a security checkpoint operator interface adjacent portal 330.

Portal 330 includes stationary platform 332 arranged to support person 322 and overhead motor/drive subsystem 334. Under the control of subsystem 340, subsystem 334 is configured to controllably slide each of two arrays 336 along corresponding guide rods 337 up-and-down with respect to vertical axis VA. Correspondingly, arrays 336 each follow a generally straight, linear path on opposite sides of person 322 and are each included within a corresponding opposing panel 338. Fig. 10 shows one of panels 338 in greater detail utilizing a partial cut-away view. In system 320, subsystem 340 is configured the same as subsystem 40 of system 20, is likewise arranged to perform procedure 120, and can include a transceiver and/or switching tree as appropriate. However, during performance of procedure 120, the operation of subsystem 340 accounts

for the movement of array 336 relative to person 322 in a linear, translational manner instead of a rotational manner as described in connection with system 20. System 320 can include one or more encoders (not shown) operably coupled to system 340 and/or other devices/techniques to track position of arrays 336 relative to platform 332. System
5 320 can further include a communication subsystem (not shown) the same as subsystem 60 to remotely communicate with subsystem 340.

In one particular arrangement, panels 338 are spaced apart by about 1.22 meters and a frequency sweep in the Ku-band from about 12.5-18 GHz is performed to provide a lateral resolution of about 1 centimeter and a depth resolution of about 2.7 centimeters.
10 For this arrangement, arrays 336 each include two subarrays of about 56 elements each that are arranged back-to-back. One subarray is dedicated to transmission and the other subarray is dedicated to reception within each array 336. In one form, each subarray is fabricated with slot-line antennas spaced apart from one another by about 2 centimeters. During operation, each subarray is electronically scanned from element-to-element as the
15 scanner moves rapidly over the vertical length of person 322. As the array moves, a number of scans are performed with array 336. During each scan, only one element of the transmitting subarray is illuminating the person and only one element of the receiving subarray is collecting reflected electromagnetic radiation at any given time. Accordingly, each transmitting element and each receiving element is activated in accordance with a
20 desired sequence during the scan. In a FM/CW heterodyne transceiver configuration of this arrangement, the 5.5 GHz frequency sweep is performed in about 12.75 microseconds. In still other embodiments, a different number, size, or type of linear array arrangement can be utilized as would occur to those skilled in the art. In still other

examples, different types of rotating and/or linear scanning arrays can be utilized separately or in combination. System 320 can be used to generate one or more cross-sectional views of person 322 and/or utilize one or more other approaches described in connection with the embodiments of Figs. 1-8 to address privacy concerns.

5 Fig. 11 illustrates interrogation system 420 of another embodiment of the present invention. System 420 illuminates person 422 with selected electromagnetic radiation in the manner described in connection with system 20. For system 420, person 422 is wearing clothing articles 424a and 424b that hide object 425. As in previously described embodiments, system 420 can be used to interrogate inanimate objects as well.

10 System 420 includes scanning booth 430 coupled to control and processing subsystem 440. Scanning booth 430 includes stationary platform 432 arranged to support person 422 and frame 433 to support motor 434 coupled to array 436. In contrast to the platform rotation of portal 30 and translational movement associated with portal 330, scanning booth 430 selectively rotates array 436 about rotational axis R and platform 432
15 during interrogation. For this arrangement, array 436 follows a generally circular pathway to provide a corresponding imaginary cylinder about platform 432. In one form suitable for scanning a person in the standing position, the radius of this cylinder is about 1 meter. Array 436 is otherwise configured the same as array 36.

 In system 420, subsystem 440 is configured the same as subsystem 40 of system
20 20 and is likewise arranged to perform procedure 120 to detect objects that may pose a threat to security. However, during the performance of procedure 120, the operation of subsystem 440 accounts for the movement of array 436 relative to platform 432 instead of the movement of platform 32 relative to array 36 as for system 20. System 420 can

include one or more encoders (not shown) operatively coupled to subsystem 440 and/or other devices/techniques to track the position of array 436 relative to platform 432.

System 420 can further include a communication subsystem (not shown) the same as subsystem 60 to remotely communicate with subsystem 440. System 420 can be used to
5 generate one or more cross-sectional views of person 422 and/or utilize one or more other approaches described in connection with the embodiments of Figs. 1-10 to address privacy concerns.

Fig. 12 illustrates electromagnetic radiation interrogation system 520 of yet another embodiment of the present invention. System 520 illuminates person 522 with
10 selected electromagnetic radiation of the type previously described. For system 520, person 522 is wearing garments/clothing designated by reference numerals 524a and 524b that conceal object 525. As in previously described embodiments, system 520 can be used to interrogate animate or inanimate objects.

System 520 includes scanning booth 530 coupled to control and processing
15 subsystem 540. Scanning booth 530 includes frame 533 arranged to receive person 522 and support array 536. In contrast to the linearly oriented arrays 36, 336, and 436 of previously described systems 20 and 420, array 536 is arranged as a ring or hoop generally centered with respect to centerline vertical axis CVA. A number of
20 electromagnetic radiation transmitting/receiving elements are arranged in a generally circular pathway along the ring. These elements operate to interrogate person 522 with electromagnetic radiation including one or more wavelengths in the millimeter, microwave, and/or adjacent wavelength bands. Array 536 is arranged for translational movement along axis CVA to scan person 522 as represented by travel arrow T. One or

more motors or other prime mover(s) (not shown) are utilized to selectively move array 536 along axis CVA.

Referring further to the partial top view of Fig. 13, array 536 is sized with opening 537 to receive person 522 therethrough as array 536 moves up and down along axis CVA. In Fig. 13, axis CVA is generally perpendicular to the view plane and is represented by crosshairs. With the vertical motion of array 536, an imaginary cylinder is defined about person 522 in accordance with the circular path defined by the array ring; however, neither person 522 nor array 536 is rotated relative to the other, instead translational movement of array 536 is used to scan person 522 vertically.

Subsystem 540 is configured the same as subsystem 40, and is operable to perform procedure 120, except that processing of subsystem 540 is adapted to account for the vertical translational movement of array 436 with its circumferential arrangement. System 520 can further include a communication subsystem (not shown) the same as subsystem 60 to remotely communicate with subsystem 440. Like previously described embodiments, system 520 is used to detect concealed objects as explained in connect with procedure 120.

Compared to array 36, a larger number of transmitting/receiving elements is typically needed for array 536 to have a comparable resolution to previously described embodiments. In one comparative nonlimiting example, between 500 and 2000 transmitting/receiving elements would be desired for array 536 versus 200 to 600 for array 36 for comparable resolution, depending on the frequency band selected. However, under appropriate conditions, scanning booth 530 can perform a scan substantially faster than portal 30. In one nonlimiting example, the scan time for portal 30 is in a range of

about 10 to 20 seconds versus about 2 to 5 seconds for scanning booth 530. System 520 can be used to generate one or more cross-sectional views of person 522 and/or utilize one or more other approaches described in connection with Figs. 1-11 to address privacy concerns.

5 In a further embodiment of the present invention, the body undergoing interrogation and the array both move. In one such example, array elements are arranged in an arc segment that can move vertically while the body rotates. In other examples, both the array and body rotate and/or translationally move. The processing of interrogation data can be adjusted for these different motion schemes using techniques
10 known to those skilled in the art.

 As described in connection with system 220, the interrogation and corresponding image information may not correspond to the full circumference of the body undergoing interrogation. Instead, the segment of interest can be less than 360 degrees. For such
15 embodiments, the image information can be interpolated by combining data corresponding to two or more different view angles. Alternatively or additionally, less than the full height, width, and/or length of the subject may be scanned in other embodiments. For such alternatives, the array size and/or scanning pattern can be correspondingly adjusted.

 In still other embodiments of the present invention, the image data gathered with
20 system 20, 220, 320, 420, and/or 520 corresponds to a number of cylindrical images without combining some or all of the images together to provide a topographical representation. Instead, the cylindrical images are used without being combined or only partially being combined. In yet other embodiments, imaging may be completely or

partially noncylindrical in nature with or without a degree of combining to provide a topographical representation.

In one further embodiment, the image information is obtained in accordance with procedure 120 and/or system 20, 220, 320, 420, or 520 is additionally utilized to identify an individual. One form of this embodiment includes a technique to control access to a restricted area, comprising: scanning an individual attempting to gain access to the restricted area; determining whether the individual is concealing any objects from the scan; comparing one or more aspects of the corresponding image information regarding features of the individual to data stored for those permitted access to the restricted area; and allowing access to the restricted area by the individual if there is a favorable comparison and no suspicious concealed objects are indicated. The determination of a match can be used to activate a gate or other access control device.

In another embodiment, image information gathered with system 20, 220, 320, 420, and/or 520 is additionally or alternatively used to identify individuals for which access should not be permitted, such as suspected criminals, known terrorists, and the like. In one more variation of such embodiments, one or more other biometrics (such as a fingerprint, palm print, retina image, vocal pattern, etc.) of the individual are compared in addition to the topographical representation data as part of the determination of whether to allow access. The features used for identification can be changed for each access to reduce the likelihood that the access control measures will be circumvented.

Alternatively or additionally, object detection in accordance with the present invention can be used to determine if an individual is taking an object from an area without

permission to do so. Any of these embodiments can be provided as a method, apparatus, system, and/or device.

All publications and patent applications cited in this specification are herein incorporated by reference as if each individual publication or patent application were
5 specifically and individually indicated to be incorporated by reference. Further, any theory, mechanism of operation, proof, or finding stated herein is meant to further enhance understanding of the present invention, and is not intended to limit the present invention in any way to such theory, mechanism of operation, proof, or finding. While
10 the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only selected embodiments have been shown and described and that all equivalents, changes, and modifications that come within the spirit of the inventions as defined herein or by the following claims are desired to be protected.